

Evidence for Multiple Pulse Shape Changes During the Third Chromatic Timing Event of PSR J1713+0747

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ABSTRACT

Millisecond pulsar J1713+0747 recently underwent a drastic change in its pulse shape. The pulsar has undergone two previous “chromatic timing events,” frequency-dependent changes in pulse arrival times, with some evidence for low-amplitude achromatic changes in the pulse shape. Ongoing monitoring efforts of the pulsar show that the latest significant shape change has persisted for several months, longer than the recovery of the behavior in previous events. I examine profiles from the Nançay Radio Telescope presented in Astronomer’s Telegram #14642 and find evidence for multiple profile shapes after the start of the third event, hinting at the possibility of several new mode changes to consider.

Keywords: pulsars: individual (PSR J1713+0747)

1. INTRODUCTION

The millisecond pulsar (MSP) J1713+0747 is a bright pulsar that has been used in tests of general relativity (e.g., [Zhu et al. 2019](#)) and the search for low-frequency gravitational waves. It is one of the most sensitive components of pulsar timing arrays (PTAs), observed by all contributors to the International Pulsar Timing Array (IPTA; [Perera et al. 2019](#)) collaboration. The IPTA is composed of four collaborations itself: the European Pulsar Timing Array (EPTA; [Desvignes et al. 2016](#)), the Indian Pulsar Timing Array (InPTA; [Joshi et al. 2018](#)), the North American Nanohertz Observatory for Gravitational Waves (NANOGrav; [Alam et al. 2021a,b](#)), and the Parkes Pulsar Timing Array (PPTA; [Kerr et al. 2020](#); [Reardon et al. 2021](#)), with affiliated observers from China and South Africa.

While its times of arrival (TOAs) have been precisely measured, PSR J1713+0747 has undergone several unusual chromatic timing events in which the TOAs have been dramatically shifted in frequency, constrained to a span of a few days (see [Lam et al. 2018](#) for more information). The first event is consistent with purely dispersive delays though older data quality does not give strong constraining power. [Lam et al. \(2018\)](#) analyzed the second event in NANOGrav data and found it consistent with interstellar propagation effects, with follow-up work by [Lin et al. \(2021\)](#) finding similar; the latter group also found low-amplitude *achromatic* pulse shape variations and could not explain this phenomenon. [Goncharov et al. \(2021\)](#) however find chromatic timing delays in PPTA

TOAs that are inconsistent with propagation effects. They also find an associated profile shape change, pointing to a magnetospheric origin of the event. Events of these characteristics and amplitudes are unseen in other MSPs so far.

[Xu et al. \(2021\)](#) recently announced a shape change in the pulse profile of PSR 1713+0747 with an association to possible chromatic changes in the pulse arrival times. The change in the profile’s linear polarization as detected by the Five-hundred-meter Aperture Spherical Telescope (FAST) suggests an intrinsic rather than interstellar origin. Other groups have confirmed the event with other telescopes ([Meyers & Chime/Pulsar Collaboration 2021](#); [Singha et al. 2021](#)).

2. DATA AND ANALYSIS

I analyzed the profiles presented by [Xu et al. \(2021\)](#) to examine how the pulse shapes of PSR J1713+0747 change over time after the start of the third event. They show time- and frequency-averaged profiles from a dense monitoring campaign from the Nançay Radio Telescope taken at 500 MHz with roughly daily cadence after the event started sometime between MJD 59319 and 59321. Six profiles are shown prior to the event with 21 following its start, with a clear difference in the shapes between the two sets seen by eye.

The highest signal-to-noise (S/N) ratio pulse after the start of the event was observed on MJD 59335. I used this data profile and generated a smoothed template profile using the PYPULSE software package ([Lam 2017](#)), in which I iteratively fit Gaussian pulse components until the residual profile was below 0.5% of the maximum amplitude. I then used a Fourier-transform-based template matching procedure ([Taylor 1992](#)) to align the 21 profiles. With the best-fit scale factor for the template also measured from this procedure, I sub-

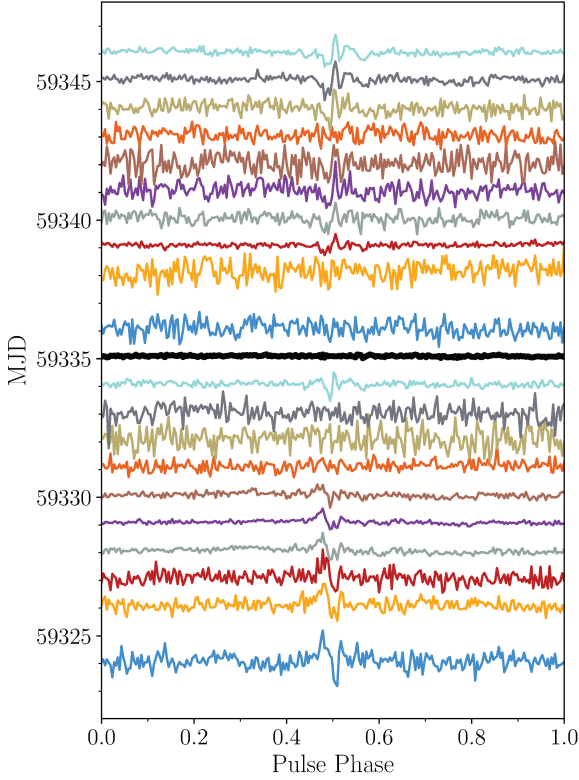


Figure 1. Residual profiles as a function of observing epoch. The profile used to generate the template is shown with the thick black line.

tracted the scaled template from the data profiles. Figure 1 shows these residual profiles.

Three different modes are apparent in Figure 1. The first several residual profiles show an increase followed by a dip, the second set mostly shows white noise (no change from the template used), and the third set show a decrease followed by an increase. Inspection of the pulse profiles by eye shows that the new component trailing the main component is “notched” differently between epochs and may account for some of these differences when using the profile alignment technique above. Future per-component analyses may be able to better disentangle which components show temporal variations.

I further investigated these modes by generating four distinct templates, using the procedures above on the 6th, 11th, 17th, and 27th pulse profiles (MJDs 59319, 59329, 59335, and 59346), representing the shapes of the original pulse profile and the potential new modes during high S/N observations. I fit each of these four templates to every data profile and calculated the residual profiles as above. I computed the likelihood value $\mathcal{L}$ assuming that the residuals should be Gaussian-distributed. In comparing the log-likelihoods, I see

that there is large support for three modes plus the original shape as expected. The data from the first six epochs before the event overwhelmingly prefer the original template shape. The next six epochs prefer the first mode, as expected from the sustained shape in Figure 1. The next eight prefer the second mode along with the pulse on MJD 59343 (fourth-to-last), while the remaining six prefer the third mode. Note that the notched structure on the pulse from MJD 59334 (prior to the one used for the template) is similar to those seen in the third mode. The likelihood analysis does prefer the second mode with a $\Delta \ln \mathcal{L} \approx 2.7$; in terms of the Akaike Information Criterion there is greater than a 10:1 preference but a more thorough analysis of the profiles and generation of templates is justified.

3. DISCUSSION

While diffractive scintillation can weight different narrowband parts of the profiles during averaging such that shape changes occur in the average pulse due to intrinsic chromatic profile evolution, the persistent nature of these shape changes between epochs suggests diffractive scintillation cannot cause the changes observed. Similarly, pulse phase jitter causes subtle shape variations but is uncorrelated in time.

Singha et al. (2021) show TOAs from seven epochs after the start of the third event, fitting an exponential recovery to the baseline pre-event timing model with varying frequency dependence. They find an achromatic model is preferred, again suggesting against a propagation-effect origin to the event. Note that of the seven epochs, six appear consistent with a single jump - perhaps an epoch at one mode followed by more at another mode? A comparison of the shapes between these epochs will help validate or invalidate the possibility of mode changes. Also note that their Figure 1 does show a slight change in intensity for the BAND5 (1360 MHz) data across phase compared to later epochs though a more careful analysis is warranted.

Given the importance of PSR J1713+0747 in the detection of nanohertz gravitational waves, maximizing coverage of observations of this long-term event will be key to enable continued use of this pulsar. Since all PTA collaborations observe PSR J1713+0747, continued high-cadence monitoring and combination of datasets within the IPTA framework to look for possible shape changes, previous or ongoing, will be a critical enterprise.

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